NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MODELING SOUND AS A NON-LETHAL WEAPON IN THE COMBAT^XXI SIMULATION MODEL

by

Joseph D. Grimes

June 2005

Thesis Advisor:	Jeff Crowson
Second Reader:	John Willis

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2005	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Title (Mix case letters) **Modeling Sound as a Non-Lethal Weapon in the COMBAT^{XXI} Simulation Model**			**5. FUNDING NUMBERS**
6. AUTHOR(S) Grimes, Joseph D.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) TRADOC Analysis Center Monterey, CA			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release, distribution is unlimited			**12b. DISTRIBUTION CODE**
13. ABSTRACT (maximum 200 words)			

Modeling and representing combat and individual soldiers is a complex task. Several factors influence combatant behavior. Using non-lethal methods has become one way for combatant commanders to accomplish their wartime mission. Current the Army and Marine Corps models are not capable of non-lethal weapon replication. The Training and Doctrine Command Analysis Center (TRAC) Monterey California has funded a program of research related to individual combatant representation in modeling and simulation. Modeling non-lethal weapons was identified by TRAC-Monterey as important to better represent actual combat. This thesis used COMBAT^{XXI} , a high-resolution, closed-form, stochastic, analytical combat simulation, to replicate non-lethals and study the effects on individual combatants. Existing source code was modified to model the Long Range Acoustic Device (LRAD), the non-lethal platform chosen for this research. LRAD is an acoustic device designed to modify the behavior of personnel with a high intensity warning tone. Once the LRAD capability was developed, a scenario was developed to test the simulated effects of the device. A model was developed to accurately determine behaviors of individual combatants. It was concluded that the implementation of this new non-lethal capability in COMBAT^{XXI} improved the model and created a more realistic representation of actual combat conditions.

14. SUBJECT TERMS combat modeling, behavior rules, long range acoustic device, modeling and simulation, non-lethal weapons, algorithm			**15. NUMBER OF PAGES** 61
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

MODELING SOUND AS A NON-LETHAL WEAPON IN THE COMBAT^{XXI} SIMULATION MODEL

Joseph D. Grimes
Major, United States Army
B.S., Jacksonville State University, 1992
Master of Education, Armstrong Atlantic State University, 2003

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2005

Author: Joseph D. Grimes

Approved by: Jeff Crowson
Thesis Advisor

Major John Willis
Second Reader

James N. Eagle
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Modeling and representing combat and individual soldiers is a complex task. Several factors influence combatant behavior. Using non-lethal methods has become one way for combatant commanders to accomplish their wartime mission. Current the Army and Marine Corps models are not capable of non-lethal weapon replication. The U.S. Army Training and Doctrine Command Analysis Center (TRAC) Monterey California has funded a program of research related to individual combatant representation in modeling and simulation. Modeling non-lethal weapons was identified by TRAC-Monterey as important to better represent actual combat. This thesis used COMBAT^{XXI}, a high-resolution, closed-form, stochastic, analytical combat simulation, to replicate non-lethals and study the effects on individual combatants. Existing source code was modified to model the Long Range Acoustic Device (LRAD), the non-lethal platform chosen for this research. LRAD is an acoustic device designed to modify the behavior of personnel with a high intensity warning tone. Once the LRAD capability was developed, a scenario was developed to test the simulated effects of the device. A model was developed to accurately determine behaviors of individual combatants. It was concluded that the implementation of this new non-lethal capability in COMBAT^{XXI} improved the model and created a more realistic representation of actual combat.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ATC	American Technologies Corporation
COMBAT^{XXI}	Combined Arms Analysis Tool for the 21st Century
db	Decibel
HMMWV	High Mobility Motorized Wheeled Vehicle
LRAD	Long Range Acoustic Device
MOE	Measures of Effectiveness
M&S	Modeling and Simulation
NIOSH	National Institute for Occupational Safety and Health
NPS	Naval Postgraduate School
SME	Subject Matter Expert
SPL	Sound Pressure Level
TRAC-Monterey	TRADOC Analysis Center – Monterey
TRAC-WSMR	TRADOC Analysis Center – White Sands Missile Range
TRADOC	Training and Doctrine Command

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

First and foremost I would like to thank Almighty God for allowing me to have this opportunity to further my education and do something positive for the military and this country that I love. Without Him, none of this would have been possible. I would also like to thank Dr. Jeff Crowson for being my thesis advisor and for allowing me the latitude to take this thesis in the direction that I wanted. His advice was instrumental in getting me on the right track to success. I would like to thank Major John Willis, TRAC-Monterey for his work as my second reader. He was instrumental in getting my thesis completed and his advice, counsel and friendship was and is very much appreciated. Thanks to all who supported me in this adventure.

This thesis would not have been possible if it had not been for Dr. Imre Balogh. Dr. Balogh was instrumental in every aspect of this research by implementing my ideas into COMBAT^{XXI} . His masterful ability to write code and make COMBAT^{XXI} produce the results that I needed were indispensable assets to me and this project. I would also like to thank LTC Tom Cioppa for bringing this subject to my attention and for his advice along the way. He and his team supported this work from the first day and provided mentorship and the funding necessary for me to complete my project. Thank you all.

Last but certainly not least, I want to thank my wife Kristen. She has sacrificed more during this process than anyone. She was willing to be second place behind my work for the duration of this project. It takes a strong character to do that and for that I am eternally grateful to her and thank her for her loving support throughout my career. She is the reason I do what I do every day.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Modeling and representing combat and individual soldiers is a complex task. The current military simulation models have limited applications because they cannot fully represent all aspects of combat. In an effort to enhance the capabilities of combat simulation models, the Training and Doctrine Command Analysis Center – Monterey (TRAC-Monterey) is the proponent for a funded program of research related to individual combatant representation in modeling and simulation (M&S). The representation of non-lethal weapons has been identified by TRAC-Monterey as an important area of research. This representation was the focus of this thesis research.

Sonic weapon technology is not new but it is relatively new to military applications. The Long Range Acoustic Device (LRAD) is the sonic weapon of choice on today's battlefield. The LRAD can be used for behavior modification when lethal means of behavior modification are not desired. Input factors and responses were chosen based upon the physiology of the human ear and the capabilities of the LRAD. Three input factors were chosen and a model was developed to represent them in the Combined Arms Analysis Tool for the 21st Century (COMBAT^{XXI}). These factors were: LRAD intensity, range to target, and individual position relative to LRAD beam. Each of these factors has two input levels that yield eight possible scenarios. Each scenario has a certain probability depending on the combination of factors. Using data resourced from the U.S. Navy 5th Fleet LRAD usage report, a probability matrix was devised to cover all possibilities. Common sense was applied to this matrix and minor changes were made as necessary to make a more logical matrix. The individual combatant must react in some way when impacted by LRAD. The reactions developed were: no reaction, alter behavior, or incapacitate. There are several other possible input factors and reactions that could be modeled but this thesis focuses on the aforementioned three input factors and reaction.

The model was developed using the input factors and reactions as a basis. An algorithm was developed that modeled the flow of data in the simulation. The following figure is a representation of the algorithm used to implement this model.

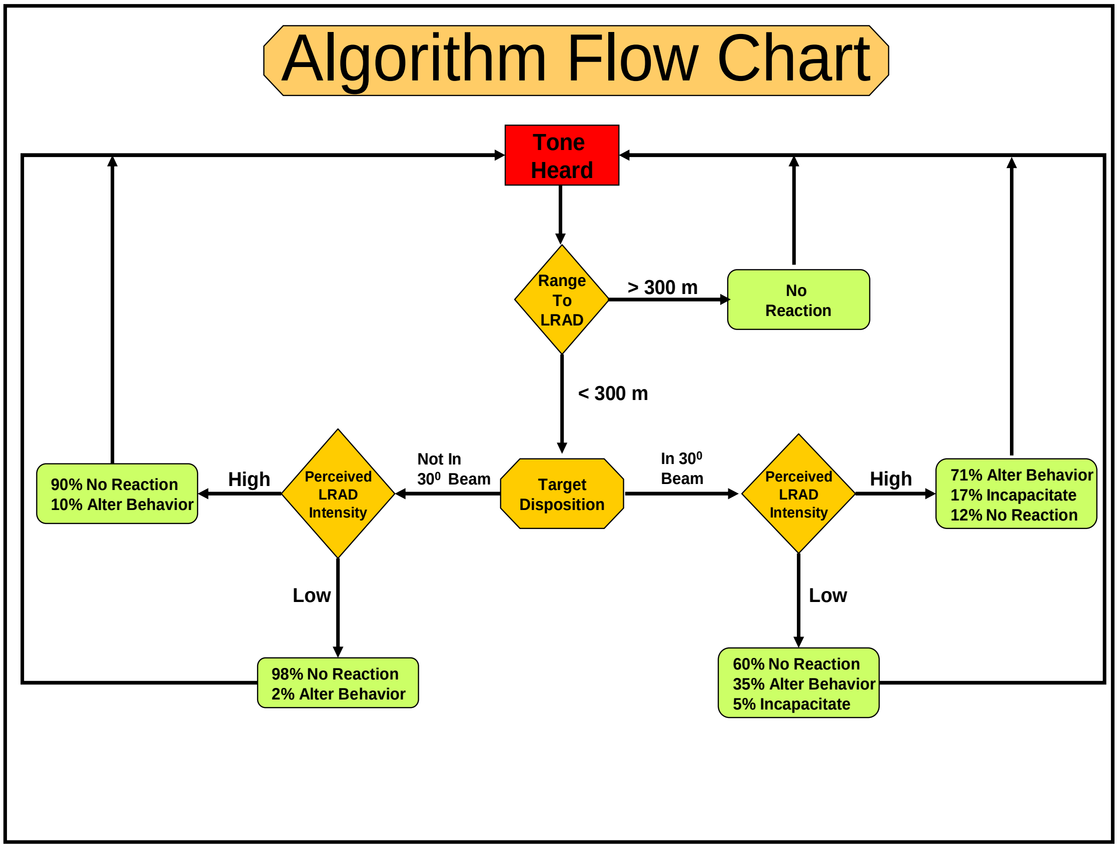

Figure 11. Algorithm Flow Chart

This model was used to develop behavior rules in COMBAT^{XXI}. The simulation was not capable of representing non-lethal weapons. Existing source code had to be modified in order to accurately represent LRAD in COMBAT^{XXI}. The algorithm and probability matrix were used to create behavior rules for individual combatants as well as rules for use of LRAD as a non-lethal weapon platform. As a result of these modifications to COMBAT^{XXI}, users of the simulation now have the option to use LRAD as a non-lethal capability and enhance the way COMBAT^{XXI} models actual combat. Another result of this research is the ability for the simulation to model urban terrain and to model radar jamming equipment. These two capabilities were not modeled previously.

A scenario was developed in close cooperation with Dr. Imre Balogh at TRAC White Sands Missile Range that tested the new behavior rules in actual simulation environments. Several runs were conducted with and without the behavior rules in place to determine is the model was working in the simulation. It was determined that the individual combatants did in fact modify behaviors when LRAD was utilized as a non-lethal weapon in COMBAT^{XXI}. The data output retrieved from the simulation clearly indicated a significant difference in the statistical data between the runs. The base case runs were completed without LRAD capability and the red force overwhelmed the blue force. The low and high case runs showed significant differences in the number of kills obtained by the red force against the blue force and the number of total casualties inflicted by the blue force against the red force. The conclusion is that the LRAD makes a significant difference in the number of casualties each side receives. The statistics also show that the LRAD served as an effective non-lethal capability as the number of casualties is significantly reduced (over 80% for each force) in runs using LRAD. This new capability will allow users of COMBAT^{XXI} to have a more realistic simulation environment in which to conduct training.

The face validation technique was used to determine the validity of the model. It was determined that the model implemented in COMBAT^{XXI} seemed reasonable and logical and therefore met the criteria for face validation. Implementing this model enhanced the capabilities of COMBAT^{XXI} and created a more realistic simulation.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Modeling combat is a complex undertaking. A number of factors impact soldier behavior in combat operations. Additionally, a large variety of conventional and unconventional weapons are used on today's modern battlefield. The use of non-lethal methods in combat has become one way for commanders to accomplish their wartime missions with less cost in terms of human lives. Non-lethal weapons also allow commanders to take live prisoners for questioning whereas dead enemy forces represent a loss of potential intelligence information. Non-lethal weapons can also be used to modify the behavior of the enemy in order to persuade him to move in a certain direction, to a certain area, or halt his operations indefinitely.

The models currently in use by the U.S. Army and the Marine Corps are not able to replicate non-lethal weapons and the subsequent response by the individual combatant. The current service transformation efforts have placed emphasis on modeling and simulation (M&S) to replicate military capabilities in terms of both the individual combatant and new weapon technologies.

Sonic weapons are currently being fielded by the Army and the Marine Corps in theaters of operation around the world. The use of sonic weapons can give the commander on the ground another tool to use against a current or future enemy. The purpose of this thesis is to develop the capability to replicate non-lethal weapons in the Combined Arms Analysis Tool for the 21st Century simulation model (COMBAT^{XXI}) specifically the use of the Long Range Acoustic Device (LRAD). To test this capability once developed, data will be collected from COMBAT^{XXI} simulation runs to determine how an individual combatant reacts when exposed to the LRAD. The simulation data will be compared to a US Navy data base developed from the use of LRAD on ships. The assumption is that the enemy threat on the ground will react in a manner comparable to an enemy threat in a small boat.

The Army has determined that the capability to represent non-lethal weapons in the COMBAT^{XXI} simulation model is an area that must be explored. This thesis will explore current and future non-lethal capabilities and implement these capabilities into

the COMBAT^{XXI} system. Doing so will produce a simulation that is more representative of non-lethal weapons and their effects.

A. BACKGROUND

The Training and Doctrine Command (TRADOC) Analysis Center in Monterey, California (TRAC-Monterey) is the proponent for a funded program of research related to individual combatant representation in modeling and simulation (M&S). The use of non-lethal weapons is an important area of research that has been identified by TRAC-Monterey under this program. The approach that will be used is the development of a scenario in the COMBAT^{XXI} model to represent the use of the LRAD. Once this capability is developed and refined, the model would become more realistic and useful to commanders, policy makers, and writers of doctrine.

COMBAT^{XXI} is a high-resolution, closed-form, stochastic, analytical combat simulation. It is being continually refined and developed by the TRADOC Analysis Center – White Sands Missile Range (TRAC-WSMR) and the Marine Corps Combat Development Command (MCCDC). COMBAT^{XXI} is a replacement for several older and less capable models that have been in use for several years.

TRAC-WSMR has identified a need to develop a non-lethal weapons capability in COMBAT^{XXI}. This capability can be implemented in the simulation by using a set of behavior rules. This analysis seeks to develop a general model of sonic non-lethal weapons, and then implement a version of that model in COMBAT^{XXI} using a set of behavior rules. Simulation data will be collected and compared to actual data from the field to determine if the simulation accurately replicates actual individual behavior.

B. SCOPE AND ASSUMPTIONS

Non-lethal weapons are not currently modeled in the COMBAT^{XXI} simulation. The reaction of individual combatants to non-lethals in a simulation has never been studied to date. Sonic non-lethal weapons technology is very new to the U.S. military. However, the battlefield employment of sonic weapons is increasing rapidly among the services. The Long Range Acoustic Device (LRAD), developed by American Technologies Corporation, is the sonic weapon of choice at the current time. LRAD has been used in the Afghanistan and Iraq theaters of operation as well as in many ports around the world by the U.S. Navy. The technology is new and has been used in the

military services for three to five years. The first use of the device was on naval vessels after the bombing of the U.S.S Cole. The other services have just begun to see the potential of this device and do not currently have any data available about its effectiveness against human targets. However, the Navy has kept records of LRAD's use on naval vessels, primarily against small boats driven by potential threat personnel. This thesis assumes that the human response to LRAD employment by ground forces is comparable to that of personnel aboard water craft. This assumption is essential to this study as reaction probabilities will be based upon data gathered by the U.S. Navy. The final goal of this study will be to determine how to effectively model the LRAD and then determine if the individual combatants react in a deterministic way in the COMBAT^{XXI} simulation.

C. BENEFITS OF THIS STUDY

This study will introduce the use of non-lethal weapons and their effect on the individual combatant in the COMBAT^{XXI} simulation model. These weapons are being employed on today's modern battlefield and have been used with some effectiveness. Introducing these type weapons into the simulation model will allow analysts to estimate how effective these weapons can be and provide insight on how to employ them against a future enemy. This data will also allow analysts to estimate the effect of sonic weapons employed against BLUE forces.

D. HISTORICAL OVERVIEW

The use of disconcerting noise to unsettle the enemy is hardwired into most higher animals, from the warnings and battle roars of confrontational animals to the trumpets, drums, bugles, bagpipes, devilish war cries, taunts and piercing shrieks used by humans in their conflicts. An example from Hollywood is that of Lieutenant Colonel Kilgore in 'Apocalypse Now!' [Ref 4] blasting Wagner from his Cavalry helicopters. Moving from film to recent history, consider how General Noriega was bombarded with endless cycles of high-volume hard rock music when he sought refuge in the Vatican Embassy in Panama, as were the Branch Davidians during the fateful siege at their compound in Waco. Possibly the earliest account in Western literature of sound itself being used as a weapon can be found in the Bible. Joshua 6:5 gives us the account where Joshua leads an attack on the city of Jericho (c1400 BC) during which he commands his

people, outside the walled city, to remain in total silence for seven days. On the seventh day, seven trumpets made from ram's horns give a "long blast", the people shout… and the walls of Jericho come crashing down [Ref 10].

The ideology behind "non-lethal" weapons is not new. Police have used chemical sprays and rubber bullets, to name just two, to quell domestic riots in the US throughout the 1960s. A second-wave of non-lethals were introduced in the Gulf War and later, in Somalia in 1994: sticky foams to adhere a person to an object or another person; caustics to dissolve tires and roadways; lasers to disorient and temporarily blind; acoustic weapons that used high-decibel noise to cause pain, or infrasound to cause unbearable nausea. The United States had already discovered while dropping bombs over Vietnam, that sudden, high-decibel noise would deafen people, though this was not what non-lethal researchers had intended. (The 1907 Hague Convention prohibited the use of "arms, projectiles, or materials calculated to cause unnecessary suffering.") But it presented an interesting question: Was it possible to project sound at a precise decibel level that caused pain without permanent ear damage? Furthermore, there was anecdotal evidence suggesting that at the right frequency, infrasound would "liquefy a person's bowels and reduce them to quivering diarrheic masses."[Ref 11]

In 1957, inventor/robot scientist Vladimir Gavreau, attempted to build a low-frequency weapon after accidental exposure to infrasound. While working in a concrete building that housed his laboratory, he and his fellow researchers periodically became debilitatingly nauseous. He discovered that the nausea ceased when certain windows in the building were blocked. Eventually, engineers traced the problem to an improperly installed motor-driven ventilator that activated an infrasonic resonance in a large duct where it was located. The motor, coupled with the rest of the concrete building, itself a large enclosure, formed an infrasonic amplifier. Shutting the windows altered the resonance of the building and shifted its infrasonic pitch. Gavreau, convinced he had discovered a new weapon, created several replicas of the original air duct. He pumped different frequencies of sound through massive ducts 6 feet in diameter and 75 feet long. When exposed to the infrasound, the researchers felt a "pressure against the eyes and ears...their internal organs were filled with continual painful spasms...and every pillar and joint of the massive structure bolted and moved."[Ref 11]

The history of sonic weapons, coupled with a need for the military to have the capability to control combat conditions without causing permanent casualties, has led to the development and deployment of the current sonic technologies. These new technologies take into account the facts and assumptions that early developers of these weapons discovered in their research. The purpose of this historical overview is to provide a knowledge base and map for the development of these weapons.

Figure 1. Long Range Acoustic Device

Figure 2. Relative Size of LRAD v/s Soldier

Figure 3. LRAD Used for Crowd Control

II. SONIC TECHNOLOGY OVERVIEW

A. LONG RANGE ACOUSTIC DEVICE

1. LRAD Technological Overview

The **Long Range Acoustic Device** (*LRAD ™)* developed by American Technologies Corporation (ATC) is a flat panel, multi-transducer, phase coherent emitter. It transmits highly directional voice and warning tones with clarity and authority in excess of 500 yards over water and 300 yards over land. The LRAD transmits a focused beam of less than 30 degrees. The LRAD accepts Microphone, VRT, MP3, CD and other audio devices. It is resistant to corrosion and designed for a robust operational environment with solid-state electronics. Power requirements are less than 500 watts, and the device can be operated with an inverter and a vehicle battery.

The LRAD is technically <u>not</u> a weapon. It is a non-lethal capability, and is safe when properly used to both those in the beam and the operator. LRAD has been evaluated by an independent test lab, field tested, with operational practice set to perform within the guidelines of National Institute for Occupational Safety and Health (NIOSH) for combined noise exposure source levels and durations.

The LRAD supports the efforts of the armed services and Homeland Security agencies to defuse potentially hostile or dangerous situations by communicating voice instructions, plus reinforcing them and influencing behavior with a highly irritating warning tone. LRADs are being employed to determine the intent of an individual or individuals approaching members of the armed forces and installations, assets, or vehicles guarded/operated by them. The LRAD is being configured in a remote operated, ruggedized pan/tilt/zoom mount to support high value asset and infrastructure protection from a central security system as a “remote sentry”.

The LRAD puts distance between a potential threat and friendly troops, increasing reaction time to deal with challenges resulting from the small boat threat, hostile crowds, check point operations, area denial of personnel, and clearing buildings. It is hoped that LRAD will save lives on both sides of the device. [Ref 2]

FEATURES

- Highly Directive Loudspeaker Device
- Clear Voice 300 - 500 yds
- Warning Tones 500 - 800 yds
- All-Weather, manual or remote operated acoustic device
- Man-portable device
- Vehicle/building/stand-alone, 50 Cal mountable
- 120VAC, battery or AC/DC inverter, 500 W generator
- Microphone (dynamic voice)
- Audio input via MP3, CD, VRT, Laptop, etc.
- Voice Response Translator allows multi- language communications

Figure 4. LRAD Features

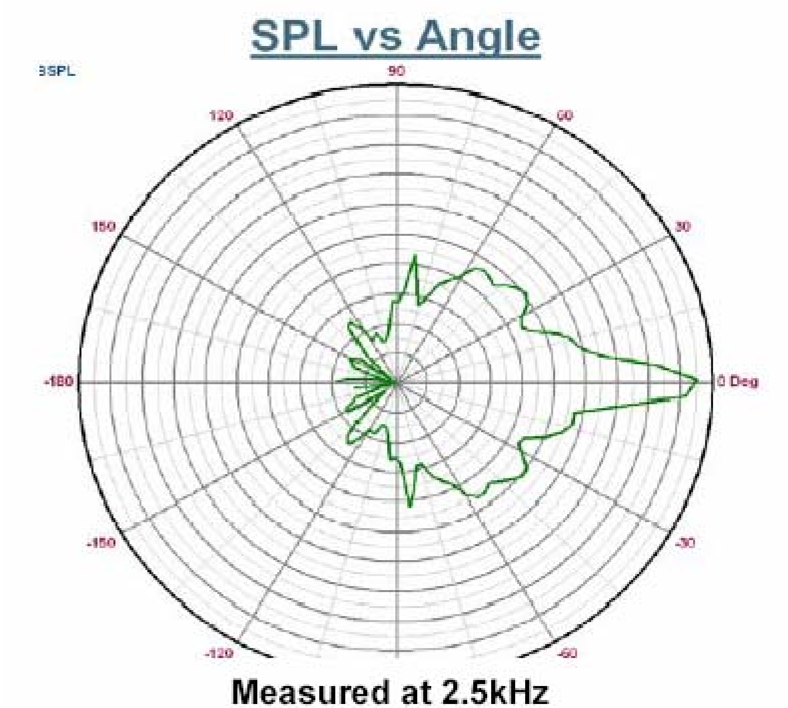

Figure 5. Directional Nature of LRAD Sound Pressure Level vs. Angle

LRAD 3300 SERIES TECHNICAL SPECIFICATIONS

Weight :	Approximately 45 Lbs
Diameter:	33" Diameter X 5" Thickness
Maximum SPL Tone:	146 dB sustained, 151 dB burst at 1 meter
Maximum SPL Voice:	Less than 120 dB sustained, based on individual voice frequencies and harmonic characteristics
Regulated Power Mode:	Normal operations, tone limited to 120 dB at 1 meter
Durability:	Thermal conditions have minimal effect on system performance System meets MIL-STD 810 environmental specifications
Emitter, Harmonic Distortion:	Less than 1% THD at 126 dB at 1 meter at 2.5kHz
Maximum Power Handling:	500 watts; 90-250VAC at 50-60Hz, 6 Amps
Normal Power Usage (Tone):	240 watts
Directionality:	-20dB at +/- 15degrees at 2.5kHz

Figure 6. Technical Specifications

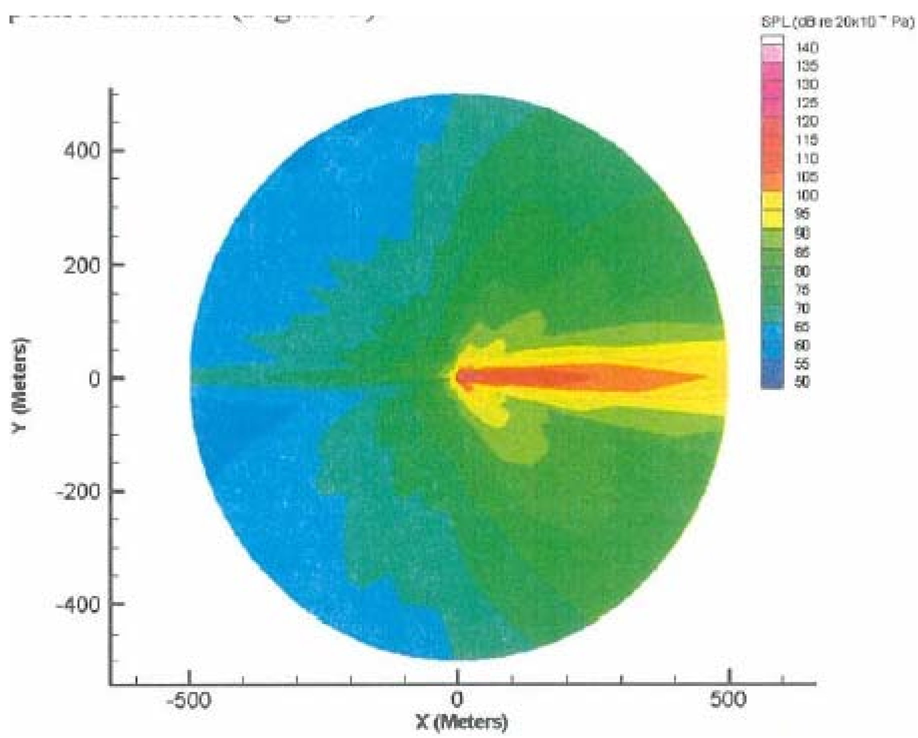

Figure 7. Directionality of LRAD

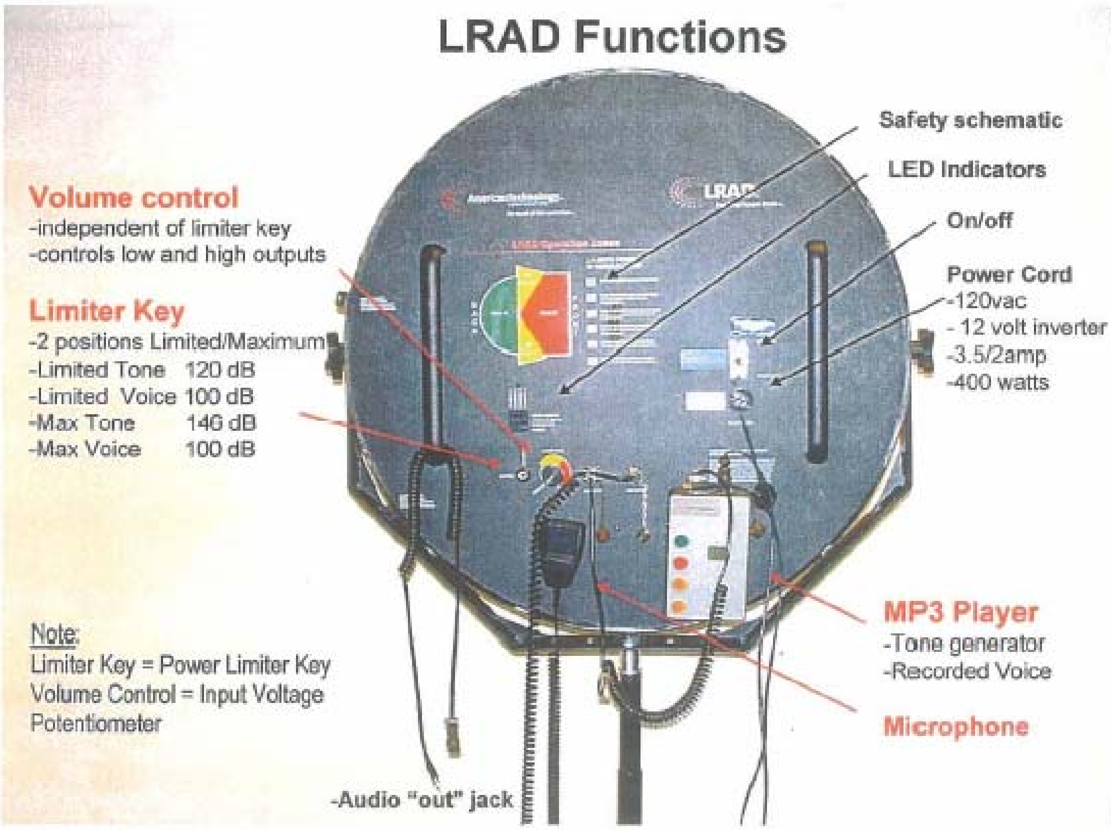

Figure 8. LRAD Function Schematic

III. INPUT FACTORS

A. INDIVIDUAL REACTION TO LRAD

1. Combat Conditions

a. Hearing Protection

Despite significant differences in many human characteristics, hearing is relatively the same in all humans. Persons with hearing loss are less likely to hear sounds at lower levels but high intensity noise can still cause pain in the human ear. The LRAD is a device that is most effectively employed against individuals that are not wearing hearing protection. Individual combatants will be classified in the COMBAT^{XXI} simulation as either having or not having hearing protection.

b. LRAD Intensity

The intensity of sound produced by the LRAD is a factor to be considered. Individual reaction to high intensity sound, (e.g. over 100 decibels) versus a lesser noise level, (e.g. less than 80 decibels) is very different. High intensity noise will generally cause an individual to alter his behavior, whereas lower intensities might just be bothersome. Intensity can be adjusted between high and low accordingly, depending on the mission of the friendly forces.

c. Range to Target

The range to the target from LRAD is an important factor that must be considered, because the decibel level of LRAD abates as range increases. Range will determine the intensity of LRAD in the COMBAT^{XXI} simulation. Figure 9 (below) shows how the decibel level of LRAD at both high and low intensity decreases with range.

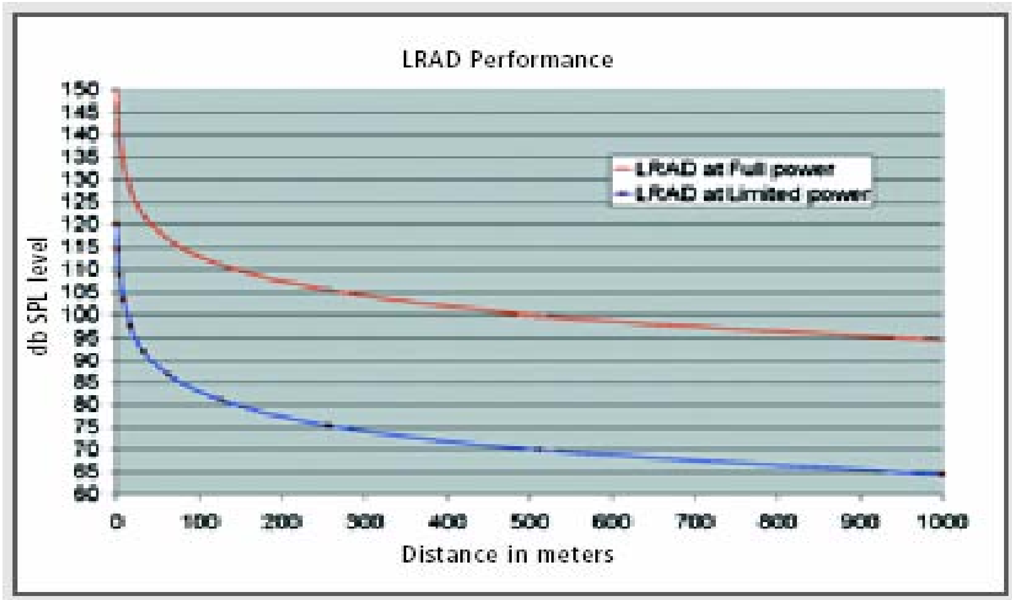

Figure 9. Sound Pressure Level Propagation vs. Distance in Meters

d. Position Relative to LRAD

The position of the individual relative the LRAD is also a factor. The LRAD is a directional device and projects a beam of sound 15 degrees around the center line of fire (or a 30 degree wide beam). If an individual combatant is in the coverage area of this beam then he will be affected by the device and if he is outside the beam then the assumption is that the individual will likely not react to LRAD.

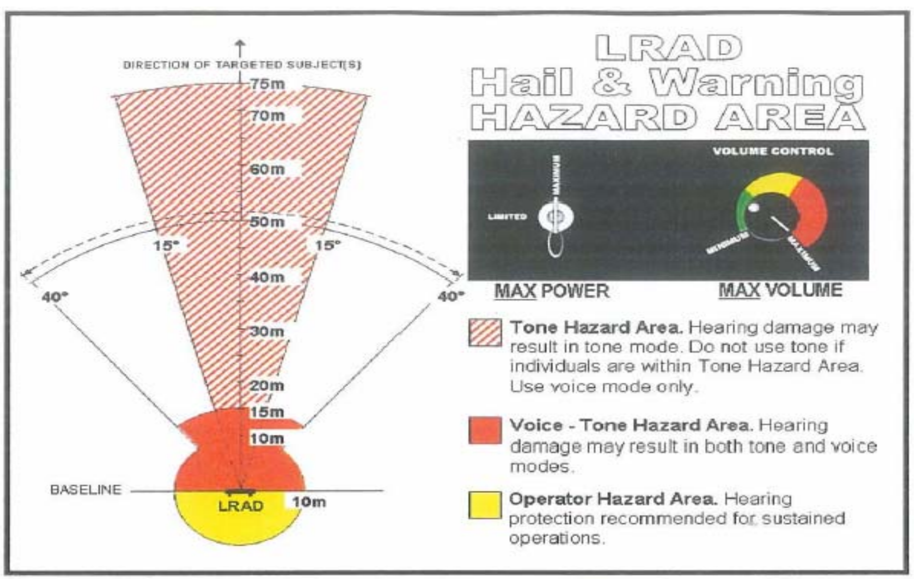

Figure 10. LRAD Beam Distribution

2. Psychological and Physiological Conditions

a. Long Term Exposure

Long term exposure to high intensity noise can cause psychological and physiological damage. It was determined by developers of sonic technologies that playing a recording backward of a human baby crying is annoying to humans, and most will try to remove themselves from the proximity of the source [Ref 9]. Couple this with the fact that high intensity noise levels can cause pain and discomfort to an individual, as well as permanent hearing loss, most individuals will choose to move out of the area or turn and run in the opposite direction entirely. Loud sounds can cause an arousal response in which a series of reactions occur in the body. Adrenalin is released into the bloodstream; heart rate, blood pressure, and respiration tend to increase; gastrointestinal motility is inhibited; peripheral blood vessels constrict; and muscles tense. On the conscious level we are alerted and prepared to take action. Even though noise may have no relationship to danger, the body will respond automatically to noise as a warning signal [Ref 5]. Long term exposure to high intensity noise has a cumulative effect on an individual's hearing. The longer you are exposed to a loud noise, the more damaging it may be. Also, the closer you are to the source of intense noise, the more damaging it is [Ref 1]. The longer an individual is in the LRAD beam, the more likely permanent hearing loss could occur. Since the sound is so intense and annoying, individuals will likely not stay in the beam long enough to cause permanent damage. The infliction of hearing loss is a non-lethal option if the individual that is being targeted is wanted for questioning and interrogation.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. THE SIMULATION, COMBAT^{XXI}

A. OVERVIEW

The Combined Arms Analysis Tool for the 21st Century (COMBAT^{XXI}) is a high resolution analytical combat simulation under development at the TRADOC Analysis Center – White Sands Missile Range, with participation by the Marine Corps Combat Development Command. COMBAT^{XXI} is primarily a tool used for the analysis of land and amphibious warfare. Specifically, future systems and doctrine are evaluated. The results from the simulation runs are used in the decision process to determine what types of systems to purchase or modify and how to change doctrine to make the best use of future system capabilities. Many of the systems modeled in the simulation are “paper systems”; in other words they do not currently exist, but the concepts for such a system do exist. This thesis focuses on the overall architecture and the development plan of the model. Specifically, how the model’s architecture will allow existing model functionality to be easily extended by the analyst, so that future systems can be analyzed. Additionally, release dates and the projected functionality for each future version of the model will be addressed. [Ref 3]

B. DEVELOPMENT AND IMPLEMENTATION OF THE MODEL

The developers of COMBAT^{XXI} have determined that the model lacks the ability to accurately model certain behaviors and weapons capabilities. The simulation currently does not have the ability to replicate any non-lethal capability. The efforts of this thesis focused on developing the capability of the simulation to replicate the Long Range Acoustic Device. Once the capability is developed for the simulation, other tangents can be explored in order to more readily replicate other non-lethal technologies, including rubber shotgun bullets, malodorants, and sticky foam, just to name a few.

The COMBAT^{XXI} design team at TRAC-WSMR assisted in defining the best approach for this project. Dr. Imre Balogh, the Sensor and Move developer for the simulation, suggested that we limit the parameters initially in order to simplify implementing the capabilities of the LRAD system and the behaviors of the individual combatants. It was decided to modify the existing source code and develop the necessary behaviors needed for the project.

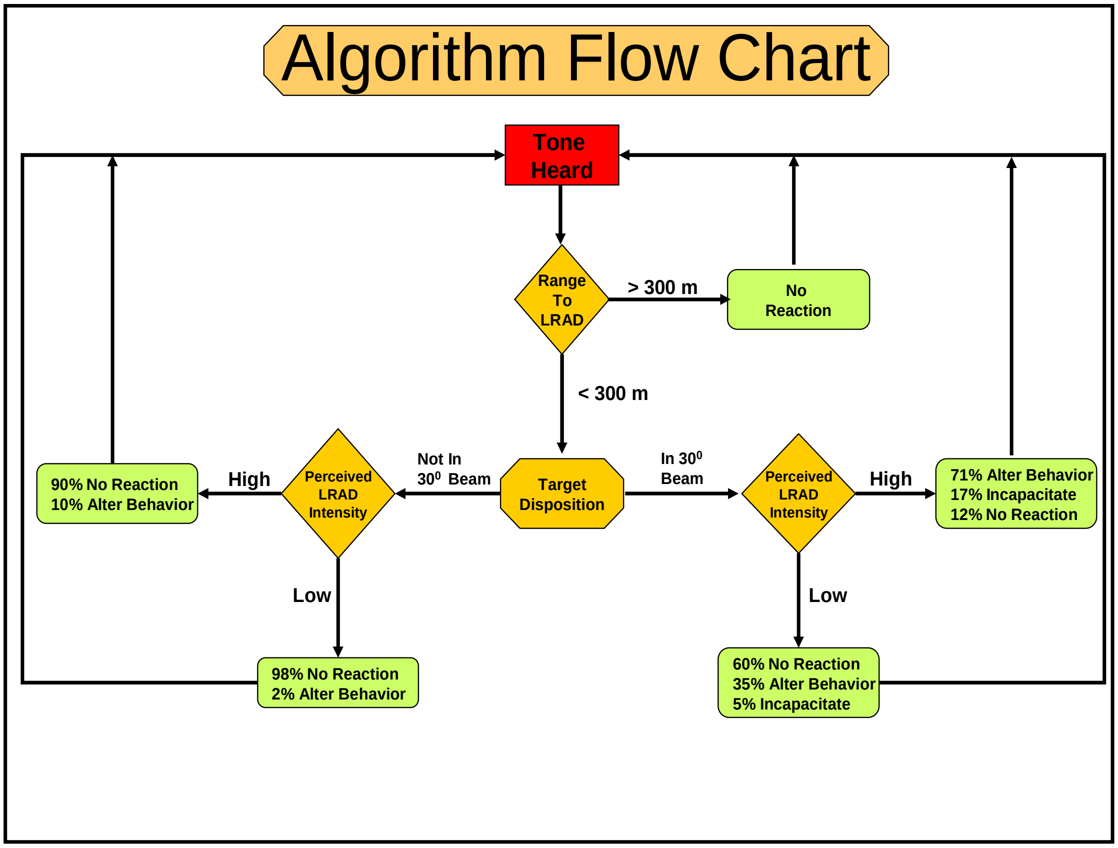

Figure 11. Algorithm Flow Chart

V. THE MODEL

The data that was collected by the U.S. Navy [Ref 6] regarding the reaction of individuals in small boats entering restricted zones around ships, helped identify input factors that affect how an individual reacts to LRAD exposure. Four input factors were identified that were significant and a model was developed to account for these. Three of the four input factors will be used to gain data from the COMBAT^{XXI} simulation. The fourth input factor should be addressed during further research and model development.

A. INDIVIDUAL COMBATANT REACTION TO LRAD

Figure 12 shows the model for the individual reaction to the LRAD device.

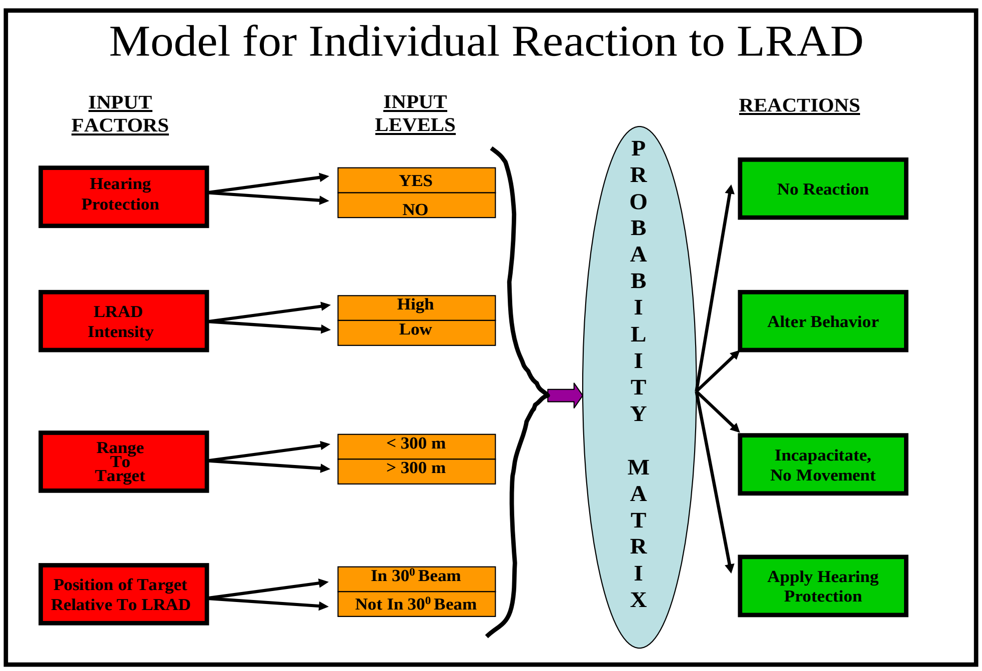

Figure 12. Individual Reaction to LRAD

Input factors were selected as a result of research performed on data from American Technologies Corporation. The device is new to the field and data is scarce, but the data obtained presented these input factors as the most significant to the user of LRAD and the individual or individuals being targeted. These input factors are not difficult to model and can be implemented into COMBAT^{XXI} with relatively little modification to existing code. The input factors have two basic levels, and each level has

an impact on the reaction in the simulation. The input factors are: Hearing protection level, LRAD intensity, range to target, and position of target relative to LRAD. These input factors each have binary levels. Figure 12 shows each level in detail. There are four responses that can occur in the simulation. An individual can: Not react, alter behavior and assume a more desirable combat posture, become incapacitated and unable to move, or apply hearing protection. The input factor "hearing protection" and the response "apply hearing protection" will not be used for this thesis research. Efforts will focus on three input factors, LRAD intensity, range to target, and position of target relative to LRAD and focus on the following responses: No reaction, alter behavior, and become incapacitated.

The model produces eight cases that we will consider. There are three input factors used each with two input levels. The probability matrix in Figure 13 (below) shows the probabilities that a given case will occur in the simulation. The factor table is binary, with 1 and 0 listed accordingly in the last column of the matrix. The probabilities used in the table are representative of real-world data collected by the U.S. Navy. Some of the probability values are estimates based on trends in the data and only estimated where actual data did not exist. These estimated values can be changed if new data becomes available or for theoretical comparison.

1. Using the Matrix

The matrix in Figure 13 is read by taking the values in the matrix and converting them into words. For example, in the event that case 4 occurred, the individual combatant being targeted would be less than 300 meters from the LRAD, would perceive that the LRAD is on high power, and would not be in the LRAD's 30 degree directed beam. In this case, the individual combatant would likely not (90% chance) react to the LRAD and continue on his present course.

Probability Matrix

Input Factors\CASE#	1	2	3	4	5	6	7	8
No Reaction	0.99	0.98	0.95	0.9	0.85	0.6	0.12	1
Alter Behavior	0.01	0.02	0.05	0.1	0.14	0.35	0.71	0
Become Incapacitated	0	0	0	0	0.01	0.05	0.17	0
	1	1	1	1	1	1	1	1

Input Factors Matrix

Input Factors\CASE#	1	2	3	4	5	6	7	8	Binary result
LRAD Intensity	1	0	0	1	1	0	1	0	1-high, 0-low
Range to Target	0	1	0	1	0	1	1	0	1<300, 0>300
Position of Target Relative to LRAD	0	0	1	0	1	1	1	0	1-in 30^0 Beam,0-not in 30^0 Beam

Figure 13. Probability Matrix for All Possible Cases

THIS PAGE INTENTIONALLY LEFT BLANK

VI. EXPERIMENTAL DESIGN AND DATA ANALYSIS

A. EXPERIMENT OVERVIEW

A scenario was developed to assess the effectiveness of the new capability of COMBAT^{XXI} to replicate LRAD and the consequent reactions by individual combatants. Several runs were conducted in order to ensure that the behaviors were effectively replicated in COMBAT^{XXI}.

B. THE SCENARIO

The terrain chosen for the scenario was urban terrain. This decision was based upon the fact that current U.S. operations are being conducted in urban terrain which includes obstacles such as buildings, parked vehicles, debris from combat, etc.

The blue force consisted of a patrol of twelve troops on foot carrying M-16 rifles and one High Mobility Motorized Wheeled Vehicle (HMMWV) with LRAD mounted on the vehicle. The mission of the blue force was to move through this terrain to an objective rally point on the opposite side.

The red force consisted of a crowd of 70 personnel; 10 insurgents with AK-47 rifles and 60 non-combatants. The crowd of personnel emerged onto the streets of the urban terrain from between buildings upon arrival of the blue force on the street and the insurgents in the crowd engaged the blue force. The blue force cannot readily distinguish between non-combatants and insurgents and engaged anyone in the crowd when they were fired upon. This scenario assumed that when a red entity was exposed to LRAD then he was incapacitated or ran to an alternate location away from the LRAD beam and was thus combat ineffective.

The following screen shots display the flow of the battle from beginning to end and show how the forces are arrayed initially, upon engagement without LRAD, and upon engagement with LRAD in the low and high modes. These screen shots only depict the entities reacting with incapacitation and not with behavior modification. Notice that the blue force patrol is wiped out totally when LRAD was not used. There are 4 casualties from the blue force when the LRAD was used on low setting and approximately the same results when LRAD was used on high setting. There were also

significantly fewer red casualties as many of them were incapacitated by LRAD, rendered combat ineffective and bypassed by blue forces.

Figure 14. Initial Force Array

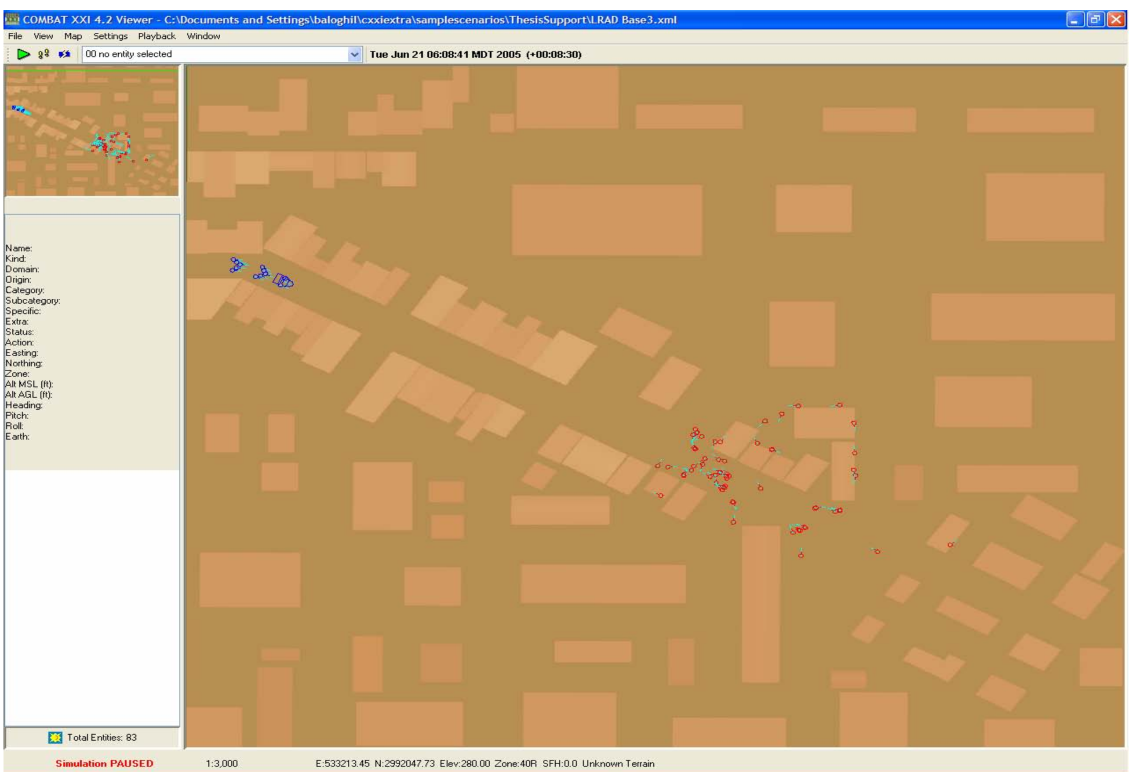

Figure 15. Crowd Beginning to Form

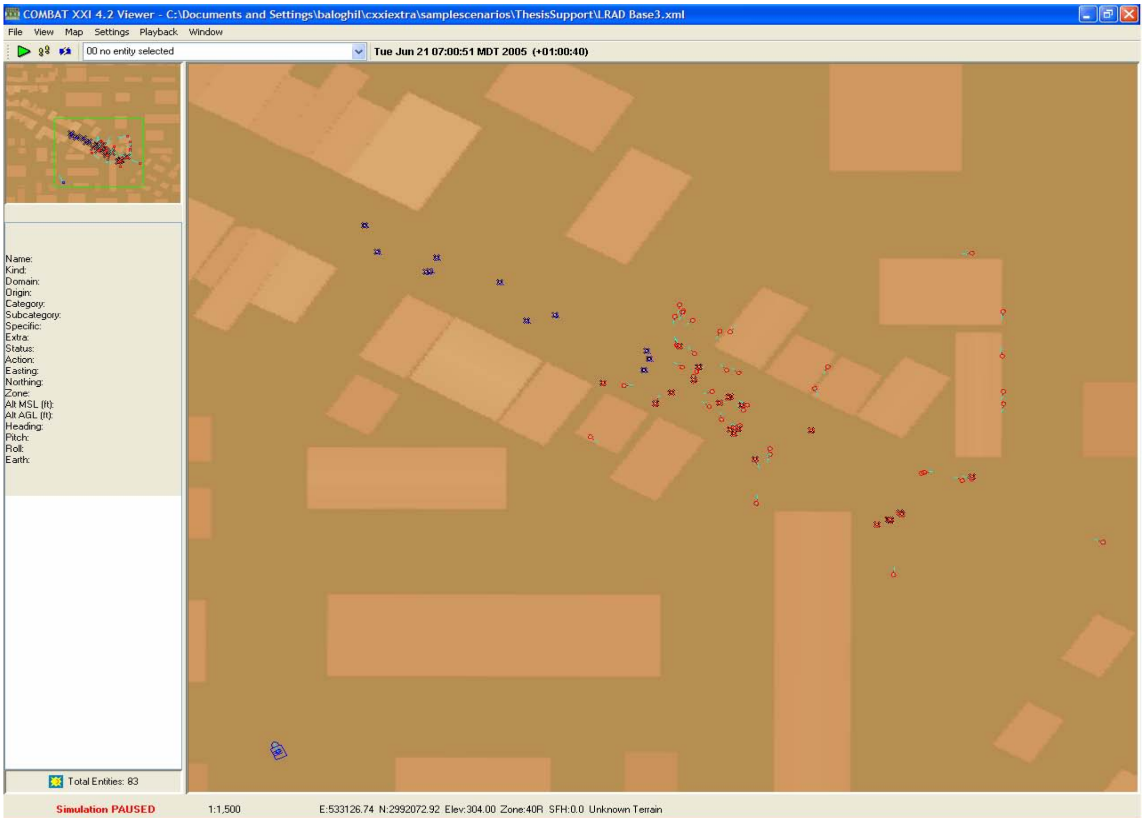

Figure 16. End State with No LRAD

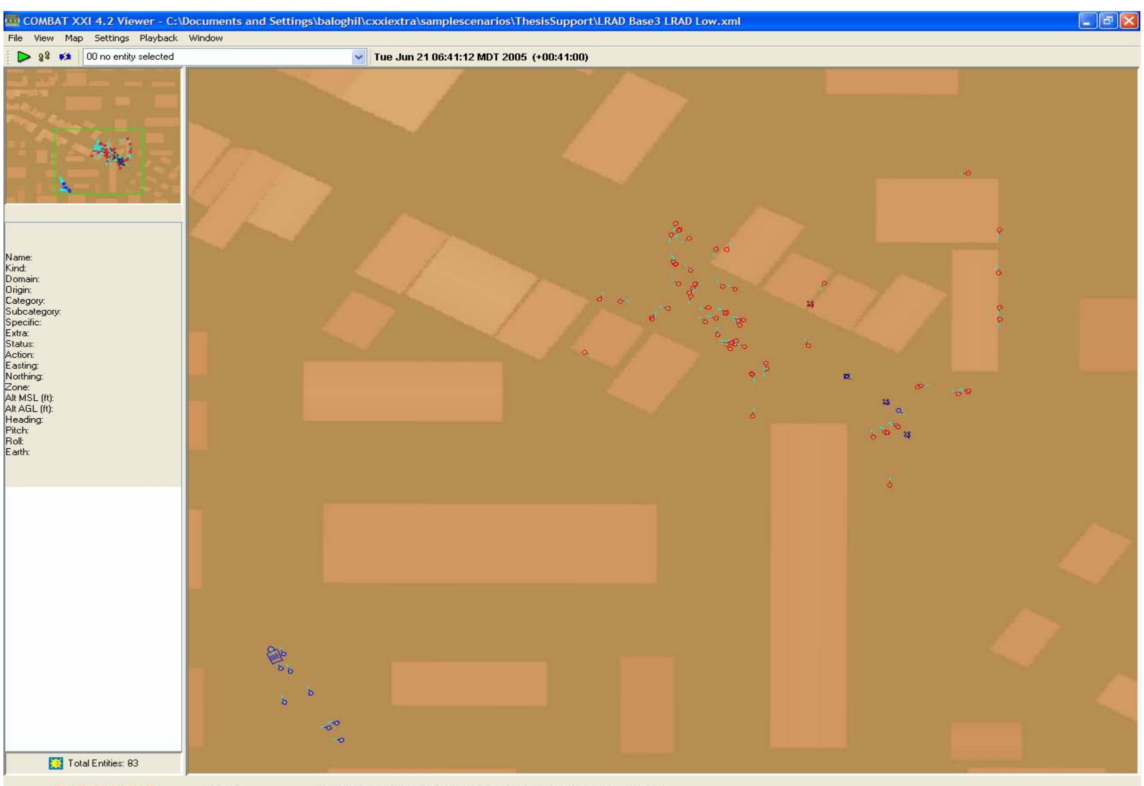

Figure 17. End State with LRAD Set to LOW

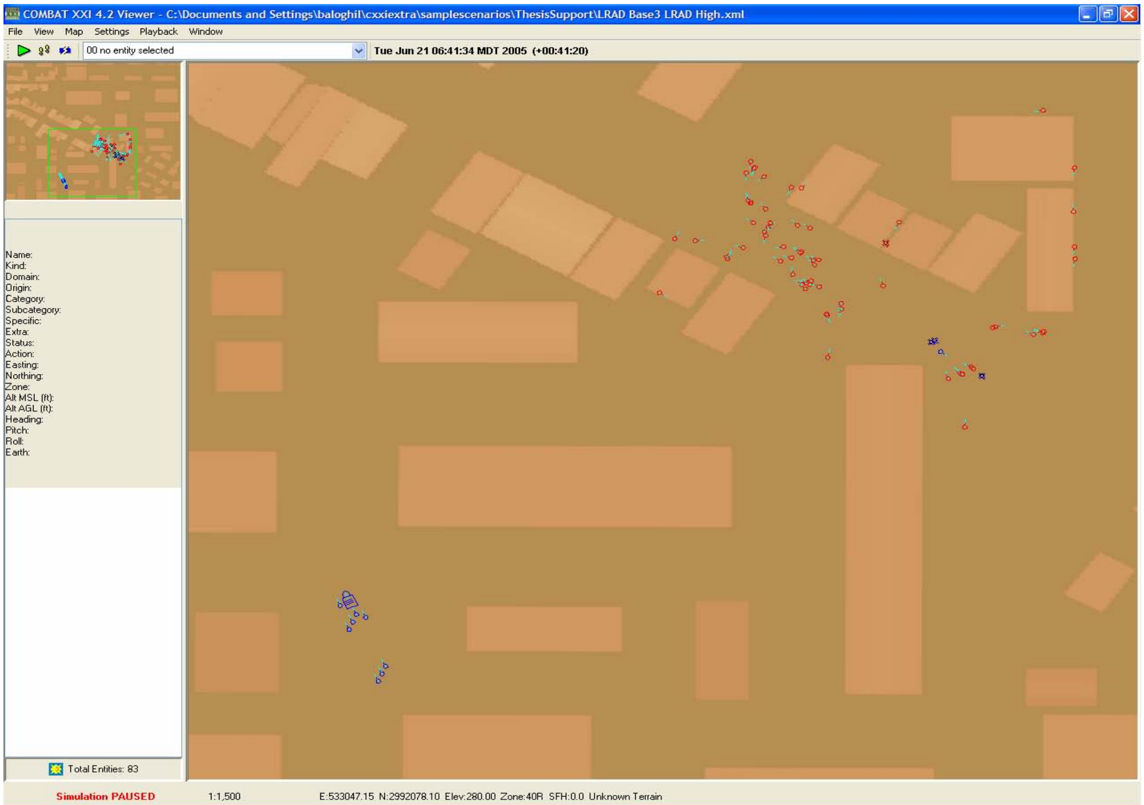

Figure 18. End State with LRAD Set to HIGH

As indicated by the last two screen shots, most of the blue force made it through to the objective rally point when the LRAD was utilized. This indicates that the non-lethal capability of the patrol resulted in far less casualties for both red and blue forces.

C. MEASURES OF EFFECTIVENESS

The mission of the blue force was to traverse the urban terrain and arrive at an objective rally point on the opposite side of said terrain. The red force emerged from between the buildings in the urban terrain and engaged the blue force. Once engaged, the blue force returned fire. The red force outnumbered the blue force in terms of personnel. The runs without LRAD had only kills recorded by blue. The runs with LRAD showed the number of red forces incapacitated or who modified their behavior. Red force incapacitation or behavior modifications were the measures of effectiveness (MOE).

D. INDIVIDUAL COMBATANT REACTION TO LRAD

Red force personnel reacted to LRAD in a manner consistent with logical assumptions. Runs conducted without LRAD showed that the red force personnel did not modify behavior and fought with blue forces until the blue forces were either killed or

retreated. Runs with LRAD showed that the red force personnel, specifically the non-combatants, did in fact show the effects of the behavior modification and left the area. The insurgents in the crowd were either killed, incapacitated or ran to a location outside of the LRAD beam. Those who ran could no longer engage the blue forces. Those that were incapacitated were no longer effective in the battle. This explained the differences in the number of blue kills with and without LRAD. This reaction to LRAD by the red force personnel appeared to be realistic and was consistent with actual data used to create the simulation behavior rules.

E. DATA ANALYSIS

The data output that was retrieved from the simulation clearly indicated a significant difference in the statistical data between the run sets. The base case runs were completed without LRAD capability turned on for blue, and the red force overwhelmed the blue force. The low and high case runs showed significant differences (less) in the number of kills obtained by the red force against the blue force and the number of total casualties inflicted by the blue force against the red force. The following table shows the differences in the average number of blue and red **killed** per run and the standard deviation and variance for each case.

No LRAD	1	2	3	4	5	6	7	8	9	10		Avg		Std Dev	Var
Blue Killed	12	12	12	12	12	12	12	12	11	11		11.8		0.42163702	0.17777777
Red Killed	10	17	7	7	10	10	8	16	21	11		11.7		4.71522357	22.2333333
LRAD Low															
Blue Killed	2	2	3	3	2	1	2	2	1	2		2		0.66666666	0.44444444
Red Killed	2	0	3	2	0	3	2	3	3	2		2		1.15470053	1.33333333
LRAD High															
Blue Killed	0	3	0	2	3	0	1	0	1	0		1		1.24721912	1.55555555
Red Killed	0	3	0	3	3	0	1	0	1	0		1.1		1.37032031	1.87777777

Table 1. Data Collection Table

The conclusion was that the LRAD made a significant difference in the number of casualties each side receives. The results also show that the LRAD served as an effective non-lethal capability as the number of casualties is significantly reduced by over 80% for red and blue using LRAD. This new capability will allow users of COMBAT^{XXI} to have a more realistic simulation environment in which to conduct training.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The focus of this thesis was to introduce the capability to replicate the use of non-lethal weapons in the COMBAT^{XXI} simulation model. This effort focused specifically on the introduction of sonic non-lethal technology in the form of the Long Range Acoustic Device [Figure 1]. The introduction of this model in the COMBAT^{XXI} simulation provided a method by which computer generated individual combatant entities could use LRAD and judge its effectiveness. This capability was dependent upon research that a fellow Naval Postgraduate School (NPS) student, CPT John Michaud [Ref 8] had completed that focused on sound localization. His work with sound in the COMBAT^{XXI} simulation allowed for the manipulation of sound localization code and the capability to replicate sonic non-lethal weapons.

Following a review of sonic weapon technology, it was determined that the best approach for simulating non-lethal technology was the replication of the LRAD. This replication required the least modification to the existing source code and reflects a technology that is currently in use by the United States Armed Forces. After studying data from the U.S. Navy 5th Fleet, it was found that the most significant factors to investigate were the intensity of the LRAD, the position of the target relative to LRAD, and the range of the target relative to LRAD. Behavior rules were implemented into the COMBAT^{XXI} source code from a probability table [Figure 13]. A scenario was developed to test the effectiveness of the new behavior rules. It was determined by the face validation technique that the new behavior rules allowed more realistic individual combatant behaviors, thus producing an improvement to the existing COMBAT^{XXI} simulation.

B. VALIDATION OF MODEL EFFECTIVENESS

The effectiveness of the model was determined using the face validation technique. It was determined that the model implemented in COMBAT^{XXI} seemed reasonable and logical and therefore met the criteria for the face validation technique. The output from COMBAT^{XXI} was evaluated using this technique and it was determined that the simulation was working in a realistic manner given the input conditions. C. F.

Hermann stated that project team members, potential users of the model, and subject matter experts (SME) should review simulation output (e.g., numerical results, animations, etc.) for reasonableness. They use their estimates and intuition to compare model and system behaviors subjectively under identical input conditions, and judge whether the model and its results are reasonable [Ref 7].

C. RECOMMENDATIONS FOR FUTURE RESEARCH

The study of the effects of non-lethal weapons is a broad topic that may never be fully understood or fully utilized on the modern battlefield. There are several types of non-lethal weapons that are currently in the United States Armed Forces' inventories. This thesis has only begun to explore the vast capability and utility of non-lethal weapons. As COMBAT^{XXI} continues to develop and mature, more and more non-lethal technologies can and should be introduced in order to make COMBAT^{XXI} a more realistic simulation that can be used to effectively model actual combat conditions and the reactions of entities.

Future research and development on sonic non-lethal weapons simulation in COMBAT^{XXI} should include additional input factors and a more random reaction algorithm based on future data collected during current LRAD operations. This thesis concentrated on the use of LRAD against an unmounted individual combatant with no cover or hearing protection. Future research should change the scenario to include use of LRAD against combatants that are inside vehicles, buildings or caves, behind cover, etc. As non-lethal weapon technology continues to evolve, COMBAT^{XXI} should continue to evolve in order to continue to accurately replicate modern combat conditions of the day.

The introduction of the modified source code in COMBAT^{XXI} that replicates the LRAD sonic non-lethal technology will allow for future introduction of other non-lethal weapons with little additional modification to the existing source code. An example of this was the development of the capability for COMBAT^{XXI} to replicate radar jamming equipment. Minor modification to the code used for LRAD will provide the capability for COMBAT^{XX} to include this radar jamming capability. Future research projects can use this new capability and develop it further for future versions of COMBAT^{XXI}.

Lastly, one additional benefit from this effort includes the development of the first approximation of urban terrain in COMBAT^{XXI} . The scenario called for urban terrain and this terrain model was not yet available in COMBAT^{XXI} and had to be developed in order to accomplish the goals of the experiment.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. DATA

Case	LRAD	blue kills	red kills
1	none	12	10
2	none	12	17
3	none	12	7
4	none	12	7
5	none	12	10
6	none	12	10
7	none	12	8
8	none	12	16
9	none	11	21
10	none	11	11
11	low	2	2
12	low	2	0
13	low	3	3
14	low	3	2
15	low	2	0
16	low	1	3
17	low	2	2
18	low	2	3
19	low	1	3
20	low	2	2
21	high	0	0
22	high	3	3
23	high	0	0
24	high	2	3
25	high	3	3
26	high	0	0
27	high	1	1
28	high	0	0
29	high	1	1
30	high	0	0

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B COMBAT^{XXI} SOURCE CODE

The following data is some of the source code that was created and/or modified to achieve the desired behaviors and capabilities in COMBAT^{XXI} . Other code was modified but the following code is most directly related to LRAD simulation and the behavior rules associated with that capability.

This behavior turns on the Jamming device if the entity has one and sets the power setting to the value passed in. If the entity that has this rule does not have the specified device a warning is output.

```
@author  Imre balogh

public class Action_4140_TurnOnJammingDevice implements RuleMappingIfc{
   public Object action(RuleInterpreter interp, Rule rule, DecisionModule dm) {
      ObserveDMI odmi = (ObserveDMI)dm.getDMManager().getDMI(DMIType.OBSERVE);

      if (odmi == null){  // we do not have the DMIs that are needed by this mapping
         cxxi.util.tools.RunTimeErrorHandler.unsupportedStateEncountered(
               "Rule: "+ rule.getName(),
               "This rule contains a mapping the requires DMIs that this entity does not have\n" +
               "Rule mapping number:" + this.getCode() + "  Observe DMIs needed\n" +
               "Entity is: " + dm.getDMManager().getCxxiEntity().getAssignedName() +
               "  Entity types is: " + dm.getPhysicalEntity().getBaseType() + "\n",
               "Rule ignored");
         return null;
      }
         // get the name of the sensor
      Object name = rule.getObject();
      if (!(name instanceof String)) {
         System.err.println("     argument passed in was: " + name);
         cxxi.util.tools.RunTimeErrorHandler.unsupportedStateEncountered("Rule:                         "+
rule.getName(),
               "This rule was passed invalid device name argument - string expected" +
               "     argument passed in was: " + name,
               "Rule ignored");
         return null;
      }
      String deviceName = (String)name;   // when other devices are added this should be updated.
      if (!deviceName.equals("LRAD")){
         cxxi.util.tools.RunTimeErrorHandler.unsupportedStateEncountered("Rule:                         "+
rule.getName(),
               "This rule was passed an unsupported device name >" + deviceName + "<\n" +
               "At this time only the LRAD device is supported", "Rule ignored");
         return null;
      }
          double powerSetting = ((Double)rule.getObject()).doubleValue();
      LRADStatePacket aPacket = new LRADStatePacket();

      if (powerSetting < 2){
         aPacket.setIntensity(LRADStatePacket.IntensitySetting.LOW);
      } else{
         aPacket.setIntensity(LRADStatePacket.IntensitySetting.HIGH);
      }
      odmi.turnOnDevice(deviceName, aPacket);
      return null;
   }

   public String getCode() { return "4140"; }
}
```

This class models the LRAD sound generation system. This is a sound generator that generates very intense sound that can be used both as a loud speaker system and as a non-lethal method to disperse crowds. This class is very specific to model for this system. If other similar systems need to be modeled, this class could be generalized by moving the embedded data to the database.

This class provides a very coarse representation at this time. A more detailed representation could be created by modeling the signal strength in more detail as a function of range an angle. The DB values are very crude approximations – they are only intended to allow access to the correct probability data.

```
@author imre.balogh
/
public class LRADSoundGenerator extends FieldEffectModelingBase{
    /**
     * pointer to the sole instance of this class
     */
    private static LRADSoundGenerator thisGenerator = null;

    /** Creates a new instance of SoundGenerator */
    private LRADSoundGenerator() {
    }
        /**
     * get the singleton instance of this class
     */
    public static LRADSoundGenerator getSoundGenerator(){
        if (thisGenerator == null){
            thisGenerator = new LRADSoundGenerator();
        }
        return thisGenerator;
    }
    double getFieldStrength(FieldEffectSystem aDevice, Location where) {
        LRADStatePacket currentState = (LRADStatePacket)aDevice.getParamPacket();
        LRADStatePacket.IntensitySetting setting = currentState.getIntensitySetting();
        if (setting == LRADStatePacket.IntensitySetting.VOICE){
            return 0.0;
        }
        if (aDevice.isOn() && aDevice.getOperableStatus()){
            // filter on Dist
            Location devLoc = aDevice.getLocation();
            double targetDist = devLoc.distanceTo(where);
            if (targetDist > 600.0){
                return 0.0;
            }
            // filter on Dir
            AbsoluteDirection devDir = aDevice.getHeading();
            AbsoluteDirection targetDir = devLoc.directionTo(where);
            double deltaDir = devDir.getAngle(targetDir);
            if (deltaDir > 0.5236){ // 30 deg in radians
                return 0.0;
            }
            // determine sector - 0 -> in 30 degree beam
            //                    1 -> in "side beam" 15 to 30 deg on both sides
            int sector = 1;
            if (deltaDir < 0.2618){
                sector = 0;
            }

            // determine range band
            //                      0 ->   0 - 300m
            //                      1 -> 300 - 500m
            //                      2 -> 500 - 600m
            int range = 0;
            if (targetDist > 300){
                if (targetDist > 500){
```

```
                range = 2;
            } else {
                range = 1;
            }
        }
        // perform the DB mapping
        if (setting == LRADStatePacket.IntensitySetting.HIGH){
            if (range == 0){
                if (sector == 0){
                    return 140.0;
                } else {
                    return 110.0;
                }
            } else {
                // beyond 300 meters
                if (sector == 0){
                    return 120.0;
                } else {
                    return 80.0;
                }
            }
        } else {
            // if we are here the setting can only be low
            if (range == 0){
                if (sector == 0){
                    return 130.0;
                } else {
                    return 90.0;
                }
            } else if (range == 1) {
                // 300 to 500 meters
                if (sector == 0){
                    return 110.0;
                } else {
                    return 0.0;
                }
            } else {
                return 0.0;
            }
        }

    } else {
        // this device is not operable or off so return a 0.0;
        return 0.0;
    }
  }

}
```

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

1. Andrade, Antonio C., M.D., Mintz, Michael L., M.D., F.A.C.S., Fisher, George H., M.D., F.A.C.S., Motes, James M., Jr., M.D., F.A.C.S., Loeffler, Paul W., M.D., F.A.C.S., & Oshman, Robert D., M.D., F.A.C.S. et al. (1996). *Noise, Ears and Hearing Protection* (12/75M ed.). Alexandria, Virginia: American Academy of Otolaryngology-Head and Neck Surgery, Inc. Retrieved March 15, 2005, from http://www.entnet.org; http://www.entassociates.com/noise.htm

2. Ballard, A. J., Williams, P. & Winter, K. (2003-2004). *LRAD, long range acoustic device*. Retrieved January/2005, 2005 from http://www.atcsd.com/pdf/LRAD.pdf

3. Balogh, I., PhD., & Harless, G., PhD. (2003). An overview of the COMBAT XXI simulation model: A model for the analysis of land and amphibious warfare [Abstract]. *Military Operations Research Society, 71*

4. Coppola, F. F. (Producer). (1979). Apocalypse now. [Motion Picture] Hollywood, California: United Artists.

5. EPA, U. S. (1973). *Public health and Welfare Criteria for noise* (Technical No. 4-73-002). Washington D.C.: U.S. Environmental Protection Agency.

6. Fleet, U.S. Navy 5th. (2004). *5th fleet LRAD usage report* (Long Range Acoustic Device Usage Data No. 04_8Aug7). Persian Gulf Region: U.S. Navy 5th Fleet. (Microsoft Excel Spreadsheet)

7. Hermann, C.F., “Validation problems in games and simulations with special reference to models of international politics,” Behavioral Science, 12 (3), pp. 216–231, 1967.

8. Michaud, J. (2005). *Sound localization for computer generated individual combatants*. (Master’s thesis, Naval Postgraduate School). (Springfield, Va: Available from the National Technical Information Service).

9. Staff, F. (2002, 24 June 2002). Sound to make an army flee. [Electronic Version]. *The Scotsman,*

10. Sutton, D. (2005). *Sonic doom.* Retrieved April/2005, 2005 from http://www.forteantimes.com/mag_info/this_issue.shtml

11. Vaisman, D. (2002). *The acoustics of war*. Retrieved February/2005, 2005 from http://www.cabinetmagazine.org/issues/5/acousticsofwar.php

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Jeff Crowson
   Naval Post Graduate School
   Glasgow Hall
   Monterey, California

4. MAJ John Willis
   TRAC-Monterey
   ME Building
   Monterey, California

5. Dr. Gordon Goodwin
   TRAC-Fort Lee
   Fort Lee, Virginia

6. Dr. Imre Balogh
   TRAC- White Sands Missile Range
   White Sands, New Mexico

7. A.J. Ballard
   American Technologies Corporation
   San Diego, California